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ABSTRACT

In most existing computer assisted instruction (CAI), the nature of the instruction would not actually require a computer. Text is presented and read, questions are asked, and then materials are presented or reviewed depending on students' answers. There are two problems with this approach: computer capabilities for interactive task simulation are underused, and the tacit requirement to present instruction and tests in text form makes learning more difficult for many tasks. These problems may be the reason that little, if any, difference in effectiveness is found between computerized and non-computerized versions of instruction. Recent emphasis in research on mental representations in learning and on work/task simulations for instruction provides a basis for what may be a significant advance in techniques for CAI design. When these ideas are coupled with advances in computer science and technology that make it easier to develop interactive task representations, substantial gains in effectiveness are possible. This paper reviews the problems and selected research and theory, and presents several examples of recent work in CAI implementation that attempt to overcome the problems. Suggestions are derived from this work for the systematic development of design technology for interactive CAI. (Author/LMM)

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Analysis of Cognitive Processes in the Specification of Interactive Instructional Presentations for Computer-based Instruction

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ABSTRACT

In most existing CBI instruction is done as it could be done without the computer. Text is given and read, questions are asked, and then, new materials or old are given dependent on the correctness of student answers. There are two problems with this approach: computer capabilities for interactive task simulation are underused, and the tacit requirement to present instruction and tests in text-form makes student learning more difficult for many tasks. These problems may be the reason that little, if any, difference in effectiveness is found between computerized and non-computerized versions of instruction.

Recent emphasis in research on mental representations in learning and on work/task simulations for instruction provide a basis for what may be a significant advance in techniques for the design of computer-based instruction. When these ideas are coupled with advances in computer science and technology that make it easier to develop interactive task representations, substantial gains in effectiveness are possible. This paper reviews the problems, selected research and theory, and presents several examples of recent work in computer-based instructional implementations that attempt to overcome the problems. Suggestions are derived from this work for the systematic development of design technology for interactive CBI.

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INTRODUCTION

Problems in Computer-Based Instruction (CBI).

For reasons that were often unclear to me, I have been somewhat dissatisfied with CBI as it developed. It seemed to add little to what could already be accomplished by means of programmed instruction or other systematically arranged instruction. For the most part, that statement holds true even today. Now I think I understand what bothered me and what creates problems in CBI. The most interesting and potentially important things a computer can do are seldom utilized. For example, although task simulations have been included in demonstrations of CBI, the bulk of the instruction is composed of verbal descriptions, questioning or testing, and providing relatively simple feedback. I'm sure that this bias has numerous sources, foremost among them the state of psychological and instructional science (Montague, Ellis & Wulfeck, NOTE 1981). A related problem is that the "interface" between the computer programs and instructional content provides additional difficulty for the student. He/she must learn how to operate the system in addition to interacting with the content itself. As long as the interface imposes additional learning requirements on the student, or inhibits the way in which students would naturally interact with materials, CBI systems will be resisted.

The tradition of using text forms as the primary means of instruction in CBI has influenced the form of most lessons and seriously limits their effectiveness. If you view most CBI, it can be seen that the instruction is done as it would be done (or could be done) from some kind of text book. A bit of text is to be read, a bit of testing is done to assess comprehension, and then, on to more text if answers are correct, or, on to some remediation or review otherwise. There are two main types of problems with this approach: 1-the computer is mostly superfluous, its main capabilities for interactive simulation are ignored; 2-the text form puts a greater load on the student's information processing capabilities.

Computer capabilities underused.

Although there are exceptions where interactive simulations were developed for various purposes, these capabilities are used infrequently. Some of these are used to teach students principles that normally would be taught in the laboratory. Most of the materials have been variants of text. I believe that this has been largely responsible for the lack of wide utilization of CBI for instructing. The use of the computer doesn't add anything much to the materials presented in a more traditional manner. Other things being equal, the CBI presentation costs more for no gain in instructional effectiveness (Orlansky & String, 1980). The use of the computer is "instructionally" superfluous. Its usefulness is determined by factors other than teaching effectiveness.

Text form makes learning difficult.

There is a "language bias" or "text bias" in instruction (Olson, 1977). Instruction is done by written text because it is traditional to do so, and not by any analysis of requirements that suggests that it is the most appropriate means. Science textbooks have been criticized for many years as providing poor support for student learning of principles and concepts (Champagne, Klopfer & Gunstone, NOTE 1981). They describe results and abstractions as facts, or theoretical statements to be memorized. The content is decontextualized, and requires the student to provide much of the context from his/her own experience or imagination. Thus, it requires extra processing by the student to understand. It is often difficult to understand experiments, results, phenomena, and principles when they are described in text form. One has to imagine events, objects, processes, procedures that are often unfamiliar, and even may be invisible. Text may be inappropriate, or at least relatively ineffective, for teaching such materials. Since text is the primary form of instruction used in CBI, its potential for other presentation forms is slighted. The traditional use of text creates a bias that seems to have limited our perspective of what instruction should be like. This perspective limits what is done in CBI. Since materials are in text form and student interactions with task representations are rare, one would not expect there to be much difference between CBI and traditional instruction. The research literature shows this. As long as the instruction is text based, and teaching is to the same specifications, little or no difference is found (Orlansky & String, 1980).

A recent paper by Bunderson, et al, (1981) reinforces this point. They suggested that the text bias, or "lexical bias" limits the approach to instructional design and development that requires the specification of performance objectives. The idea is that performance objectives described in words (in a particular format) lead naturally to testing in words in a paper and pencil format and lead to the derivation of similarly limited instruction. The implication is that this approach restricts the instructional methods used and can actually make it less like the actual tasks to be learned.

Background.

Until recently we had little understanding of cognitive processing and cognitive representations from which to derive requirements that enable us to contrive instructional presentations. I believe that situation is changing rapidly for two reasons. First, there is a growing body of research knowledge, theory and techniques of analysis that focus on people's representation of knowledge and procedures in carrying out or learning instructionally relevant tasks (Montague, Ellis & Wulfeck, NOTE 1981). Second, there have been developments in hardware, computer science and artificial intelligence that

enable models of human processes to be tested, and the development of powerful computing environments that provide tools that enable sophisticated simulations of physical systems to be done with less effort than required previously. This has significant implication for CBI in that we can better specify how we want to represent materials for students because we can better analyze cognitive processes, and we can prepare interactive teaching environments better because of developments in programming tools and hardware. It is my thesis that these developments will radically change CBI, and will produce the elusive gains in instructional effectiveness predicted for so many years.

Bunderson, et al (1981) suggest that the derivation of "Work Models" which are simulations of the terminal task(s) to be learned provide a means of improving the specification of performance objectives. Such an approach calls for designing an interactive setting where the student can converse in newly learned vocabulary, use the appropriate concepts, perform the appropriate procedures, make predictions and solve representative problems. It is this sort of approach that is described in later sections of the paper.

Objective

The objective of the following sections of this paper are to: review selected portions of the research literature involved with knowledge representation and the analysis of cognitive processes; derive implications for interactive instruction and CBI; present several examples from recent developments at our Center, and, suggest the need for systematic development of techniques derived from this kind of research to serve as a guides for improvements in instructional technology.

APPROACH

Main lines of important research

Research and theory in cognitive science provides a new view of the nature of instruction based on the disciplines of cognitive psychology and artificial intelligence which can be of particular importance in addressing the use of interactive presentations in instruction. This perspective leads us to view interactive computer-based presentation as a representational system which cannot be studied independently of the ways people represent and think about the world and the cognitive tasks with which they are confronted.

Considerable research concerned with the role of spatial representation, graphical presentation, and imagery in learning and in instructing, provide the basis for considerable advancement in instructional techniques. Progress has been made in developing representational systems and models which appear useful for describing the complicated forms of mental behavior which underlie reasoning and problem solving. One of the most

important aspects of this research is the development of useful and accurate task and cognitive analysis procedures. These procedures are useful adjuncts for more traditional task analysis procedures and provide the basis for deriving techniques for addressing the relationship of a student's existing knowledge state to the representational demands of the task structure.

Cognitive analysis.

There are four main lines of cognitive research that illustrate the important developments. For example, considerable research has revealed the important role of organization and/or schemata in learning, reading, and comprehension. Structures in the learner's mind interact with the structure of the information to be learned (e.g., Anderson, 1977, Rumelhart & Ortony, 1977, Schank, 1980, Chiesi, et al, 1979). This work suggests that a model is needed that describes the interaction between the learner's knowledge structures and the structure of the information content contained in the instructional material. This model could then be used to determine means of preparing instructional presentations.

Research on problem solving also reveals the importance of structure. The quality of a person's representation of the problem determines the adequacy of the solution (e.g., Greeno, 1977, Hayes & Simon, 1976, Simon & Simon, 1978). Novices and experts differ in aspects of their approaches to problem solutions, primarily in the level of strategic knowledge applied (e.g., Chi, Feltovich & Glaser, 1981). It is suggested that some of this knowledge can be used to structure procedures to guide novices in problem solutions (Reif & Heller, Note, 1982), and this has been shown to produce substantial improvements in performance (Heller & Reif, Note, 1982). Thus, this research also seems likely to contribute to instructional techniques.

Considerable research has studied the role of spatial representations and imagery in learning, memory and performance. For example, when told to imagine visual scenes or places, subjects learn arbitrary lists of words faster (Bower, 1970, Paivio, 1972). The "vividness" of stories enhance learning (Montague & Carter, 1974). The research suggests that imagery is powerful for learning and remembering arbitrary materials, but little systematic work has been done with more complicated subject matter or tasks. It seems unlikely that visualization will play the same role in learning complicated tasks. However, when it is important to know a special environment, experience with it, or with one similar to it, may be important (Attneave, 1974). Graphical representations of such environments may be important ways to assist in instruction.

Recent research on analogical representations shows promise for assisting instructional design. It is common practice to introduce a new topic by analogy to a familiar domain. The real question is how to choose an appropriate or good analogy. Should we rely on experts for their derivation or must we structure them appropriately for the limited understanding of novices. Analogies that elicit erroneous inferences can interfere with learning (Gentner & Gentner, 1982, Riley, NOTES, 1981, 1982). Animated visual analogies have been suggested as important in teaching invisible processes, or in understanding complex sequences of events in science (Rigney & Lutz, 1974). By providing an interactive, visual representation that can direct the student's attention to particular aspects of the process as it occurs provides a means of conveying dynamic changes in events that would otherwise be very difficult to convey (Forbus, 1981).

A representation may be described as a set of propositions about the subject matter, stated in visual terms, not verbal. It is a pictorial abstraction which visually symbolizes the critical, relevant attributes of the processes or concepts being communicated to the learner (Rigney and Lutz, 1974, p.22). To be useful or effective a representation of this type must possess these characteristics: (1) correct representation of relevant aspects of objects or relations, (2) recognizable or understandable by the learner, (3) unambiguous, and (4) provide the basis for straightforward transfer to the later task (Arnheim, 1969, Riley, NOTE 1981).

IMPLICATIONS FOR INSTRUCTION

There are some important implications for instruction and for CBI from the research on mental representations. It is clear that mental representations or models play important role in people's performance on tasks and in learning. It doesn't matter if we call these mental representations, "sets," "schemata," "semantic nets," or "mental models." They play a large and important role in determining learning and performance in most tasks.

It is my intent in this paper, to suggest that attention to these representations will lead to improvement in the means by which we instruct. In particular, I suggest that guidance can be found to structure instructional information and interactions to promote learning. How well this can be developed into a technology is uncertain, but I suggest that a considerable advance is possible. What needs to be done is to describe task conditions and performance requirements in sufficient detail for adequate mental representation, and to contrive appropriate forms of instructional representation to promote effective learning and understanding. Learning a new task depends on one's mental representations and developing skill depends on acquiring the ability to represent important features of the task. Therefore, it is important to identify the kinds of representations that learners apprehend more easily to form the basis for the

development of skill. It is necessary to be able to provide new students with representations appropriate to their level of understanding, and to provide interactions that promote learning and competency. In order to do this, it is necessary to know how people represent things to themselves at particular times, as well as how to represent good models of the systems they are to interact with.

Although the current efforts in devising adequate models for representing human cognitive knowledge structures and processes are not fully matured as scientific explanations of cognition, they provide information, perspective, and techniques of potential use in instruction. Representational systems seem to capture significant aspects of how human mental processes might operate. Through careful analysis of human actions and statements during task performance sufficient knowledge can be obtained to emulate the processes with computers. Programs of this type, even if they are not explanatory models or theories of the actual, or "real" cognitive processes and structures, can be used heuristically to help in instruction.

Examples of interactive CBI and design aids

It seems likely that the knowledge about student representations and problem solving will be combined with the capabilities in hardware and software to develop more simulation-like interactions for CBI. The use of such simulations is increasing rapidly, partly because of cost reductions, and partly because of the face validity of the simulations themselves. There are three developments in recent cognitive science and computer technologies that are examples to show how interactive CBI can be designed, and provide tools to help: (a) "Generative" or "Intelligent" CBI, (b) the derivation of analogical representations for early learning, and (c) computing aids/tools for instructional design and development. Each of these will be discussed briefly.

Generative, Intelligent CBI.

Generative CBI represents a departure from the bulk of instructional interactions currently available on computer systems familiar to most people. The idea is that the instruction is generated through interaction between some content or knowledge base, and programs that incorporate teaching methods, e.g., an instruction manager, and a monitor of the student's progress with the material to be learned. The subject matter and the instructional methods are, therefore, separate programs. The interactions are not prestructured combinations of material and instructional strategy in the usual Programmed Instruction sense. Figure 1 depicts the basic schemes. The difference between generative and intelligent CBI resides primarily in how extensive the programs are that support instruction. Models of the expert allow prediction of problem solutions that can be compared with a student's for comment. The tutor model provides for interactive

questionning or demonstration as appropriate. Finally, the student model provides a way for the program to compare particular interactions with those expected from students and monitor student progress through the content. Intelligent CBI has the goal of making the instruction resemble the interactions between a tutor and a pupil. In the examples to be discussed, techniques for representing the content or tasks to be learned are separated from techniques that represent the "theory" of teaching. The advantages are that both systems can be refined independently and the system can be responsive to student idiosyncracies(see, e.g., Brown & Sleeman, 1981, and Clancey, 1981 for more extensive discussion).

INSERT FIGURE 1 ABOUT HERE.

An example of generative CBI is under development at our Center under the direction of Dr. James Hollan. The particular content is factual information about Naval ships: their characteristics, their capabilities, and their weaponry. This knowledge base is important fundamental knowledge for Tactical Action Officers. Experience with using semantic networks as representations of declarative knowledge, plus the development of programming methods that allow structuring such networks in computer memory led to the development of ways of putting the content into a microcomputer. Then, management programs were constructed to be able to search through the knowledge base for related items. Using these programs, the interface to the student was developed as a variety of games like "Twenty Questions" or "Jeopardy" or "Flash-card" (McCandless, 1981). The modularity of this approach allows the retrieval management programs and the game interfaces to be independent of the particular content. Other content can be (and has been) substituted.

Knowledge base representation. The game programs in this software system are designed to use only the information in the data base. No other information is programmed into the games. The information is arranged in the data base as a semantic network in which each object is a node. Figure 2 graphically portrays part of the data base.

INSERT FIGURE 2 ABOUT HERE.

Nodes (objects) are connected by relations. For example, in our data base on ships, a (proposition) <kynda> <isa> <cruiser> relates two nodes. A node may participate in any number of linkages. All nodes in the database are connected to at least one other object. Thus, a semantic network is created in which any two objects are related by some combination of links. Any

content that can be expressed in this form can be substituted, i.e., is a, has a, property of, etc..

Access and retrieval functions. Various functions and procedures are made available to game writers or instructional designers to retrieve and manipulate the information in the semantic network. For example, a frequently used procedure to find information involves giving the objects and a relation and the search returns a pointer to the link if it exists. Without going into detail, all the objects and relations can be retrieved from the database by the game writer or the user. All objects associated with <kynda> can be listed. Figures 3 and 4 show other ways in which the information about a particular object in the data base can be displayed.

INSERT FIGURE 3 ABOUT HERE.

INSERT FIGURE 4 ABOUT HERE.

Interfacing to students. The procedures and retrieval functions are used by a number of programs that present the learner with a variety of "games" to assist him/her in learning the database. Figures 5 and 6 show displays at the beginning of a Twenty Questions game.

INSERT FIGURE 5 ABOUT HERE.

INSERT FIGURE 6 ABOUT HERE.

In Twenty Questions the computer may select a list of objects in a category (e.g., cruisers) and from that one object that the student is to guess. The student is given 100 points at the beginning of the game, and pays for answers to questions about the hidden item (e.g., does it have a xyz radar?). The student has commands to ask questions, see a description of any object, ask the computer for a hint, or a guess, ask for help. All these cost points. The goal is to develop a sufficient description to identify the object while maintaining a high score. The Flash Card game is a more straightforward interface with the student. Direct questions are asked about objects and their relations. The student specifies a category and the computer/tutor formulates a question. Again, the student can ask for help or hints,

but it costs points. The goal of the game is to provide facility for the advanced student to drill himself about the database. Several other games have been developed as student interfaces to the database. All games record detailed "audit trails" regarding student performance, e.g., session number, student, date, start time, game, items asked, response time, etc. Figure 7 shows one of the possible audit trails for the Twenty-Questions game.

INSERT FIGURE 7 ABOUT HERE.

These records provide the capability for comparing individual and group performance from one session to another. Particularly difficult parts of the database can be identified.

Intelligent tutoring. Intelligent CBI adds considerably to the capabilities available in generative CBI. Figure 1 indicates something about the structure of intelligent CBI. It builds upon the knowledge acquired about computer modeling and graphics to build running models of systems or other complicated knowledge bases. It will include models of experts to test or evaluate student answers, models of tutoring to provide interactive response to student queries and answers, and builds interactively, a representation of students to allow shaping the topics covered by the tutor to those appropriate for the student.

This approach leads to a qualitatively different form of training. Dr. Hollan and his group have undertaken to develop "STEAMER" as a prototype. This effort represents the state of the art in Intelligent CBI. The system consists of a graphical interface to a simulation of a 1200 psi propulsion system. Actually, there are two displays, as shown in Figure 8.

INSERT FIGURE 8 ABOUT HERE.

The graphical interface to the mathematical model provides students with an easy and natural means of inspecting and manipulating the plant simulation. The other display helps the student to select the particular aspect of the simulation he/she wants to view and enables selection of various states. The simulation is displayed as animated diagrams that can be manipulated by the student. Components such as valves, switches, and pumps can be operated and the effects can be observed on plant parameters such as changes in pressures, temperatures, and flows. In Figure 8 the bottom display shows one of the engineroom displays. The engine lube oil system is shown graphically in Figure 9.

INSERT FIGURE 9 ABOUT HERE.

The tutorial part of STEAMER is being developed piece by piece into the intelligent tutor desired. It currently includes an explanation generator to demonstrate how components work, one for teaching basic physics principles, and one to provide guidance on plant operating procedures. The mathematical model (simulation) was translated into LISP and the other components have been developed in that language. The interface is a color graphics terminal that dynamically shows the functioning of the steam plant and an alphanumeric terminal to allow students/instructors to select material to be shown. It runs currently on a stand-alone computer running the LISP programming language.

This development combines several technological developments and areas of research. First are the computer and numerical modeling techniques needed to build a portable simulation system. Important contributions come from developments in student modeling, knowledge representation systems, and qualitative reasoning. Student modeling techniques make it possible to do more than just correct errors. By using accumulated evidence about student misconceptions the system will provide tutorial assistance to help him/her understand the nature of the error. Knowledge representation techniques make it possible for STEAMER to teach the student about generic systems and procedures, and show how they apply to the specific systems he/she must operate. Recent formalization of qualitative reasoning enables the development of modeling techniques to represent the conceptual relationships that form the basis of an expert's knowledge of the operation of complex systems. These techniques make it possible for STEAMER to store and communicate to the learner the causal relations between changing events in the propulsion plant (Stevens, Roberts, Stead, Forbus, Steinberg, & Smith, 1982). It should be noted that the interactive nature of generic or intelligent CBI systems require a powerful, dedicated computer system rather than one shared by a number of users.

Analogical simulations for early learning.

As mentioned earlier, it is common in instruction to utilize analogies to teach students new matter. A main problem is that a particular analogy can help or can hinder learning depending on a number of factors. For example, the correspondence or congruence between objects and object attributes in the material to be taught and those in the analogy determines much of the analogy's effectiveness (Gentner, 1980, Gentner & Gentner, 1982). In addition, the familiarity or understandability of the relations and processes in the analogy is important (Riley, NOTES 1981,1982). Students need to understand the analogy itself before it is of much use for learning new material. Thus, in order to design analogical representations for teaching, systematic consideration of these dimensions is necessary, especially when we want to determine the best means of providing computer-run task representations to new learners. The work I would like to use as an example was developed by Riley (NOTE 1981) at the University of

Pittsburgh.

Becoming skilled in a task depends upon learning to represent important features in typical problems encountered in the task situation. But, analysis of representations of experts and novices (Chi, et al, 1981) suggest that the efficient representations of experts may be difficult for novices to learn directly (Reif & Heller, 1982). What kinds of representations can novices acquire easily that map into the task, at least at its simpler levels? Another way of asking this question is what analogical instructional forms are appropriate for new learners in a domain (cf., Gentner, 1981, Van Lehn & Brown, 1980). Riley (NOTES 1981,1982) is exploring this question with students learning basic electricity and electronics (BE/E). In the Navy's course, students have had difficulty in understanding and using the representations of the circuit relations taught in the course. Students consistently have difficulty in learning simple circuits and in solving problems. Her analysis of the errors students make suggested that the existing materials allow students to learn oversimplified rules for reasoning and these lead to errors on certain problems. This led to the idea that a different representation might be more appropriate for the new learners. It might constrain student learning to eliminate the over-simple or over-generalized rules, thereby eliminating errors and enhancing understanding and performance.

The BE/E course uses a version of the "moving crowd" analogy (Gentner & Gentner, 1982) to teach students the relations between current, voltage and resistance in simple series circuits, like that in Fig. 10.

INSERT FIGURE 10 ABOUT HERE.

Students are told to think of current as the rate at which a crowd of objects (electrons, balls) moves along a path. The voltage applied from the battery corresponds to the push or force to get the objects in motion. Resistance is to be thought of as friction, and depicted by a rough or crooked path. The moving-crowd analogy leads to some straightforward predictions about the global relations between voltage, resistance and current: (1) as voltage increases or decreases, current increases or decreases; (2) as resistance increases or decreases, current decreases or increases. The analogy makes no clear predictions about circuit relations at the level of individual resistors, however, and even leads to some incorrect predictions. For example, when current flows through a resistor, there is a drop in voltage across that resistor directly proportional to the rate of current flow and the amount of resistance. The sum of these voltage drops across all resistors in series equals the voltage applied. Furthermore, current is the same at all points in a series circuit. The current through R1 (IR1) is equal to that through R2 (IR2) and

that through R3 (IR3). This is not a prediction that clearly derives from the moving-crowd analogy. In fact, the opposite might be predicted if friction (resistance) is thought to impede or slow current flow. Thus current would be expected to slow down as it passes each resistor. Similarly, since voltage is "dropped" at each resistor, and it is what "pushes" the crowd (current), one might expect current to slow as it moves through the circuit. Both of these inferences, one based on friction the other on voltage loss, violate the global constraint that current is the same everywhere in a series circuit. Errors like these are common among students learning BE/E (Riley, NOTE 1982).

Based on the idea that a readily understandable analogy is useful to teach new systems (cf., Resnick, 1980, Van Lehn & Brown, 1979), Riley developed a graphical representation of series circuits that seems to have certain advantages. It is easily understood by students, because of its familiarity and concreteness. It graphically depicts the abstract constraints at both the global level and at the local resistors. It thus maps into the Ohm's Law equations better than the moving crowd analogy and facilitates solving problems.

A segment from this simple representation is shown in Figure 11. Voltage is represented as a stack of (poker) chips, resistors as boxes containing slots equal to the resistance.

INSERT FIGURE 11 ABOUT HERE.

This work represents an attempt to analyze cognitive processes and knowledge of students learning electronics and to derive improved representations for instructing that eliminate student misunderstandings and errors. Such work provides the basis for deriving interactive instructional presentations. Table 1 presents the circuit objects and compares two approaches to instructing students. One is the "teeming crowd" analogy commonly used in teaching basis electronics. The other is the "chips analogy" that provides an easy to understand means of communicating circuit functions and constraints.

INSERT TABLE 1 ABOUT HERE

The important point to notice is that both analogies map into the objects and relations of the circuit well at the global level. That is to say, inferences regarding the effects of changes in force (voltage), force-loss (voltage-drop), friction (resistance), and rate of movement (current), are consistent with changes in number of chips, chips/box, slots/box, and number of chips/slot, as well as with actual changes in a circuit.

However, the crowd analogy allows students to make some wrong inferences about circuits in regard to voltage drops, and current. Examples are shown in the last three rows of the table. Data from students reasoning about problems reveals that they misunderstand the relation between force (applied) and the force-loss at each circuit resistor. Force is interpreted as greater than the sum of the force-losses in the circuit. Also, there are inferences that changes in resistors at the "beginning" of the circuit affect those "downstream" but not the reverse. This leads to errors in reasoning about problems like that shown in the next to the last row of the table where, when R2 is increased, no change is expected in the force-loss at R1. The chips analogy remains consistent with circuit relations even at this level.

In a recent comparison of groups of students learning to solve circuit problems using the two different representations, we found that 85% of the chips group got such problems correct while the standard crowd group was at 50%, or about chance (Montague, Riley & Konoske, in preparation). There are three important points to understand from this work. First, that systematic analysis of the relations between analogous representations and the systems that students are to learn can reveal misunderstandings that lead students to make errors, and this makes learning difficult. Second, once this misunderstanding is identified it can be corrected, perhaps by designing a simpler, more concrete analogy. Third, it seems apparent that interactive procedures are needed to assist in probing student misunderstandings and to help correct them. It should be mentioned also that interactive procedures seem necessary because errors of misunderstanding are revealed only by a few test problems. In the current course such questions are asked infrequently (10-15% of the items). In the experimental test mentioned above, the overall test scores were little different for the groups. It was only on the "diagnostic" questions that they differed. Automated systems that can present those circuit problems and assess a student's reasoning about each part or component should provide considerable enhancement of learning. To this end, we have developed interactive simulation of the model on a microcomputer and are in the process of testing it and the power of the diagnostic testing on learning.

Aids for design of interactive instruction.

On the basis of the research literature and theorizing about how students represent materials, processes, procedures to themselves, it seems apparent that we can predict generally that computer-based interactive, graphical systems will importantly advance instructional effectiveness. Considerable work is needed to develop and refine the analytic techniques that Riley (NOTES 1981,1982) is using to serve as a basis for designing representations, but the basis is there. Another line of development is needed before it will be possible to implement such representations in interactive computer systems. These are user, or author

or teacher "tools." They allow the author to develop computer-run representations of tasks that permit diagnostic assessment of student interactions, and permit revision with relative ease.

There are two primary kinds of developments taking place that exemplify such tools. First, there are aids to instructional design and development that include advisors or coaches to assist developers in their work. Second, there are byproducts of the work in developments like STEAMER that provide powerful ways for less experienced persons to develop interactive, graphical representations for teaching. For example, graphics editors can enable instructional programmers and subject matter specialists to build and try out new representations for instruction with fractions of the effort needed heretofore. Figure 12 shows some of the powerful facilities developed in the STEAMER project.

INSERT FIGURE 12 ABOUT HERE.

In Figure 12 (top) a number of objects is shown in a menu form. The instructor can select an object from the menu, and can indicate where he wants it put on the color graphics screen. He or she can select a number of objects for a new representation, connected by appropriate pipes and valves. The "taps" in Figure 12 (bottom) are the links to the values in the mathematical model that are translated into the appropriate value or representation to be shown, e.g., a dial reading, state (on-off), or flow-rate. With this tool, entirely new displays can be designed in a very short time. By providing general tools for the generation of computer-based interactive instruction considerable amounts of time and labor can be saved and lavished on the instructional interactions and error detection. Discussion of other tools for generating graphics are contained in a book edited by Freeman (1980) and a book by Bork (1981) that includes a discussion interactive instruction by means of computer systems as well as aids for authoring.

DISCUSSION AND CONCLUSION

It is clear that research on mental representations and the analytic procedures developed in that research have important ideas for instructional design and for the implementation of interactive CBI. Concentration on the design of interactive representations, and the utilization of powerful computer programming tools will help break the text bias of CBI. This should result in big gains in instructional effectiveness. By designing appropriate representations that are task simulations, learning can be more rapid and long lasting. Although these conclusions are hopeful, it is apparent that procedures will have to be developed to guide the design of interactive simulations as well as systematic evaluation of the underlying principles.. Therefore, more formal development of the principles is needed. In

order to accomplish this, an intensive research effort is required.

Characteristics of good interactive instruction.

Interactive computer-based instruction systems must provide the cues, the opportunities for students to respond, make and correct errors, and observe the consequences of their actions. This arrangement allows students to develop appropriate mental representations of a system and/or materials to be learned. It provides a phenomenological basis for developing experience. With such presentations, they can learn to operate a system, learn its principles of operation, exercise required vocabulary and procedures, correct errors, etc.. In order to accomplish this, the representation needs to show what changes occur because of certain actions by the student. It should allow frequent and rapid practice of procedures to be learned, allow and provide corrective feedback for errors so that the errors can be eliminated.

It may also be true that systems intended for training novices and those intended to provide extensive practice or retraining for moderately competent people may need to be be designed quite differently. The need for extensive corrective feedback is substantially different for these groups. Novices need extensive guidance, and precise corrective explanation of their errors and the reasons for them, while already trained individuals may need refreshment, or may need to broaden their knowledge base for situations or of signals or events that may be encountered. Novices need relatively simplified examples of problems to facilitate learning. Normally invisible events or processes may need to be made visible in order to support understanding. The more experienced individual, on the other hand, needs to refine his skill. This may require more realistic representation of critical aspects of the task. Systematic development of these ideas is needed.

A primary idea is that CBI needs instructional task fidelity (Semple, et al, 1981). This requires that the form of the presentation be understandable to the learner, conditions be provided that support student learning, and misunderstandings be detectable by testing. Instructional task fidelity requires both the design of the appropriate representation(s) for learning, and the inclusion of the necessary learning principles that support acquisition. A major difficulty is that such design is based on learning/cognition task analysis procedures which are not yet well developed, especially for complicated tasks involving decision making and problem analysis. Systematic development of prescriptive techniques is needed. To do this, the final skills to be learned need to be specified in terms of task performance, the performance conditions, and performance standards. Also, the steps involved in apprehending the skill need to be identified. This would include the representation(s) appropriate for the

learner's competency level. Then these can be implemented into interactive CBI systems utilizing the powerful tools being developed in computer- and cognitive science.

It seems likely that these general categories represent the major conditions needed for designing interactive instruction. What is uncertain is whether a prescriptive design technology will develop quickly from this general perspective. Much basic information is needed, and recommendations need to be tested to provide a better knowledge base for a technology. What seems apparent is that by focusing design considerations on work or task representations, learning situations are likely to be more effective than otherwise. It is also apparent that to do this is difficult and labor intensive. It requires considerable task knowledge and attention to the analysis of students' cognitive processes. It requires knowledge and skill in computer science to build and use tools for implementing interactive representations. This will require a team, each skilled in appropriate areas of computer science, cognitive science and instructional science. The research and theory and attempts to design interactive instruction of the sort exemplified in this paper provide important guidance for further efforts.

REFERENCE NOTES

Champagne, A. B., Klopfer, L. E. & Gunstone, R. F. Cognitive research and the design of science instruction. Pittsburgh, PA: University of Pittsburgh, Learning Research and Development Center, 1981.

Heller, J. I. & Reif, F. Cognitive mechanisms facilitating human problem solving in physics: Empirical validation of a prescriptive model. Berkeley, CA: University of California, Physics Department and Group in Science and Mathematics Education, Working paper ES-14b, March 1982.

Montague, W. E., Ellis, J. A. & Wulfeck, W. H. After years of instructional research do we know more than grandma did about how to teach people. Invited Address, Div. C, Sect. 4, American Educational Research Association, Session 23.02, 15 April 1981. ERIC Document number:

Montague, W. E., Riley M. S. & Konoske, P. A preliminary test of an alternative analogy for teaching series circuits. San Diego, CA: Navy Personnel Research and Development Center, in preparation.

Reif, F. Cognitive mechanisms facilitating human problem solving in a realistic domain: The example of physics. Manuscript submitted for publication, 1979.

Reif, F. & Heller, J. I. Cognitive mechanisms facilitating human problem solving in physics: Formulation and assessment of a prescriptive model. Berkeley, CA: University of California, Physics Department and Group in Science and Mathematics Education, Working paper, March 1982.

Riley, M. S. Representations and the acquisition of problem-solving skill in basic electricity/electronics. Pittsburgh, PA: University of Pittsburgh, Learning Research and Development Center, 15 May, 1981. Also presented as a paper at American Educational Research Assoc. Annual Meeting, Session 23.02, 15 April 1981. ERIC Document number:

Riley, M. S. Representations and the acquisition of problem solving skill. Paper presented at Annual Meeting, American Educational Research Assoc., Session 55.21, March 1982.

REFERENCES

Anderson, R. C. The notion of scemata and the educational enterprise: General discussion of the conference. In Anderson, R. C., Spiro, R. J. & Montague, W. E. (Eds.) Schooling and the acquisition of knowledge. Hillsdale, NJ: Erlbaum Assoc., 1977, pp.415-431.

Arnheim, R. Visual thinking. Berkeley, CA: University of California Press, 1969

Atkinson, R. C. & Schiffrin, R. M. Human memory: A proposed system and its control processes. In Spence, R. W. & Spence, J. T. (Eds) Advances in the psychology of learning and motivation, Vol. 2. New York: Academic Press, 1968, pp

Attneave, F. How do you know? American Psychologist, 1974, 29, 493-499.

Bork, A. Learning with computers. Bedford, MA: Digital Equipment Corp., 1981

Bower, G. H. Organizational factors in memory. Cognitive Psychology, 1970, 1, 18-46.

Brown, J. S. & Sleeman, D. Intelligent tutoring systems. London: Academic Press, in press, 1981.

Bunderson, C. V., Gibbons, A. S., Olsen, J. B., & Kearsley, G. P. Work models: Beyond instructional objectives. Instructional Science, 1981, 10, 205-215.

Chi, M. T. H., Feltovich, P., & Glaser, R. Categorization and representation of physics problems by experts and novices. Cognitive Science, 1981, nn 1-xx.

Chiesi, H., Spilich, G. J., & Voss, J. F. Acquisition of domain-related information in relation to high and low domain knowledge. Journal of Verbal Learning and Verbal Behavior, 1979, 18, 257-273.

Clancey, W. J. Methodology for building an intelligent tutoring system. Stanford, CA: Department of Computer Science, Stanford University, Report No. STAN-CS-81-894, October 1981.

Forbus, K. D. Project STEAMER: IV. A primer on Conlan--A constraint-based language for describing the operation of complex physical devices. (NPRDC TN 81-26). San Diego: Navy Personnel Research and Development Center, August 1981.

Gentner, D. The structure of analogical models in science. Technical Report No. 4451, Bolt Beranek and Newman, July 1980.

Gentner, D. & Gentner, D. R. Flowing waters or teeming crowds: Mental models of electricity. In Gentner, D. & Stevens, A. (Eds.) Mental models. Hillsdale, NJ: Erlbaum Assoc., 1981 in press.

Freeman, H. (Ed.) Tutorial and selected readings in interactive computer graphics. New York: IEEE, Inc., 1980.

Greeno, J. G. Process of understanding in problem solving. In N. J. Castellan, D. B. Pison, & G. R. Potts (Eds.), Cognitive theory (Vol. 2). Hillsdale, N. J.: Erlbaum, 1977.

Hayes, J. R., & Simon, H. A. The understanding process: Problem isomorphs. Cognitive Psychology, 1976, 8, 165-190.

Kieras, D. E. Knowledge representation in cognitive psychology. In Cobb, L. & Thrall, R. M. (Eds.) Mathematical frontiers of the social and policy sciences. Boulder, CO: Westview Press, 1980.

McCandless, T. Computer-based tactical memorization system. San Diego, CA: Navy Personnel Research & Development Center, Technical Note 81-8, March 1981.

Montague, W. E. & Carter, J. F. Vividness of imagery in recalling connected discourse. Journal of Educational Psychology, 1974, 64 (1), 72-75.

Norman, D. A. & Rumelhart, D. E. A system for perception and memory. In Norman, D. A. (Ed.) Models of human memory. New York: Academic Press, 1970.

Norman, D. A., & Rumelhart, D. E. Explorations in Cognition, 1975. W. H. Freeman.

Olson, D. The languages of instruction: On the literate bias of schooling. In Anderson, R. C., Spiro, R. J. & Montague, W. E. Schooling and the acquisition of knowledge. Hillsdale, NJ: Erlbaum, Assoc. 1977, pp. 65-90.

Orlansky, J. & String, J. Cost effectiveness of computer-based instruction in military training. Arlington, VA: Institute for Defense Analysis, IDA Paper P-1375, January 1980.

Paivio, A. Imagery and verbal processes. New York: Holt, Rinehart & Winston, 1971.

Resnick, L. B. Syntax and semantics in learning to subtract. In Moser, J. & Romberg, T. (Eds.) Addition and subtraction: Developmental perspective. Hillsdale, NJ: Erlbaum Assoc., 1981, in press.

Rigney, J. W. & Lutz, K. A. CAI and imagery: Interactive computer graphics for teaching about invisible processes. Los Angeles, CA: Department of Psychology, University of Southern California, Technical Report No. 74, October 1974.

Rumelhart, D. E., & Norman, D. A. Analogical processes in learning. Center for Human Information Processing. Technical Report 8005. La Jolla, CA: Center for Human Information Processing, 1980.

Rumelhart, D. E., & Ortony, A. The representation of knowledge in memory. In R. C. Anderson, R. J. Spiro, & W. E. Montague (Eds.), Schooling an

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Schank, R. C. Language and memory. Cognitive Science, 1980, 4 (3), 243-284.

Schank, R. C., & Abelson, R. P. Scripts, plans, goals, and understanding: An inquiry into human knowledge. Hillsdale, N.J.: Lawrence Erlbaum Associates, 1977.

Semple, C. A., Hennesey, R. T., Sanders, M. S., Cross, B. K., Beith, B. H., & McCauley, M. E. Aircrew training devices: Fidelity features (AFHRL-TR-80-36). Wright-Patterson Air Force Base, OH: Logistics and Training Division, January, 1981.

Simon, D. P., & Simon, H. A. Individual differences in solving physics problems. In R. Siegler (Ed.), Children's thinking: What develops? Hillsdale, N. J.: Erlbaum, 1978.

Simon, H. A. The Sciences of the Artificial, M.I.T. Press Cambridge: M.A., 1969.

Stevens, A., Roberts, B., Stead, L., Forbus, K., Steinberg, C. & Smith, B. Project Steamer: VI. Advanced computer-aided instruction in propulsion engineering--An interim report. San Diego, CA: Navy Personnel Research & Development Center, Technical Report 82-28, January 1982.

VanLehn, K., & Brown, J. S. Planning nets: A representation for formalizing analogies and semantic models of procedural skills. In R. E. Snow, P. A. Federico, & W. C. Montague (Eds.), Aptitude, learning, and instruction (Vol. 2): Cognitive process analyses of learning and problem solving. Hillsdale, N. J.: Lawrence Erlbaum Associates, 1980.

Williams, M., Hollan, J., & Stevens, A. Human reasoning about a simple physical system. In D. Gentner & A. Stevens (Ed.), Mental Models. Hillsdale, N.J.: Erlbaum, 1981.

Winston, P. H. Learning by understanding analogies. Cambridge, MA: Massachussetts Institute of Technology, Artificial Intelligence Laboratory, (AIM 520), June 1979.

Table 1

OBJECT MAPPINGS

CIRCUIT(BE/E)	CROWD ANALOGY	CHIPS ANALOGY
electrons	balls	chips
battery	push	stack
resistor	rough path	box (w slots)

ATTRIBUTE MAPPINGS

CIRCUIT(BE/E)		CROWD ANALOGY	CHIPS ANALOGY
applied voltage	= Ea	force	chips/stack
resistance	= R	friction	slots/box
current	= I	rate	chips/slot
voltage drop	= Ern	force-loss=f-l	chips/box

HIGHER ORDER RELATIONS

	----global----	
CIRCUIT	CROWD	CHIPS
Ea ↑ : I ↑	force ↑ : rate ↑	chips/stack ↑ : chips/slot ↑
R ↑ : I ↓	friction ↑ : rate ↓	slots ↑ : chips/slot ↓

	----local----	
CIRCUIT	CROWD	CHIPS
Ern = Irn * Rn	f-l = rate`rn * friction`rn	chips/box= chips/slot * slots/box
Rn ↑: Ern ↑	friction`rn ↑ : f-l`rn ↑	slots/box ↑ : chips/box ↑
Ea = Er1+Er2+Er3	force = f-l`rn or force > f-l`r1+f-l`r2+...	chips/stack= chips/bx1+chips/bx2+ chips/bx3
R2 ↑ : Er1 ↓; Er2 ↑; Er3 ↓.	friction`r2 ↑: f-l`r1 →; f-l`r2 ↑; f-l`r3 ↓.	slots/bx2 ↑ : chips/bx1 ↓; chips/bx2 ↑; chips/bx3 ↓.
Ir1 = Ir2 = Ir3.	rate`r1> rate`r2> rate`r3.	chips/slot/bx1= chips/slot/bx2= chips/slot/bx3.

ERRORS DUE TO ANALOGY

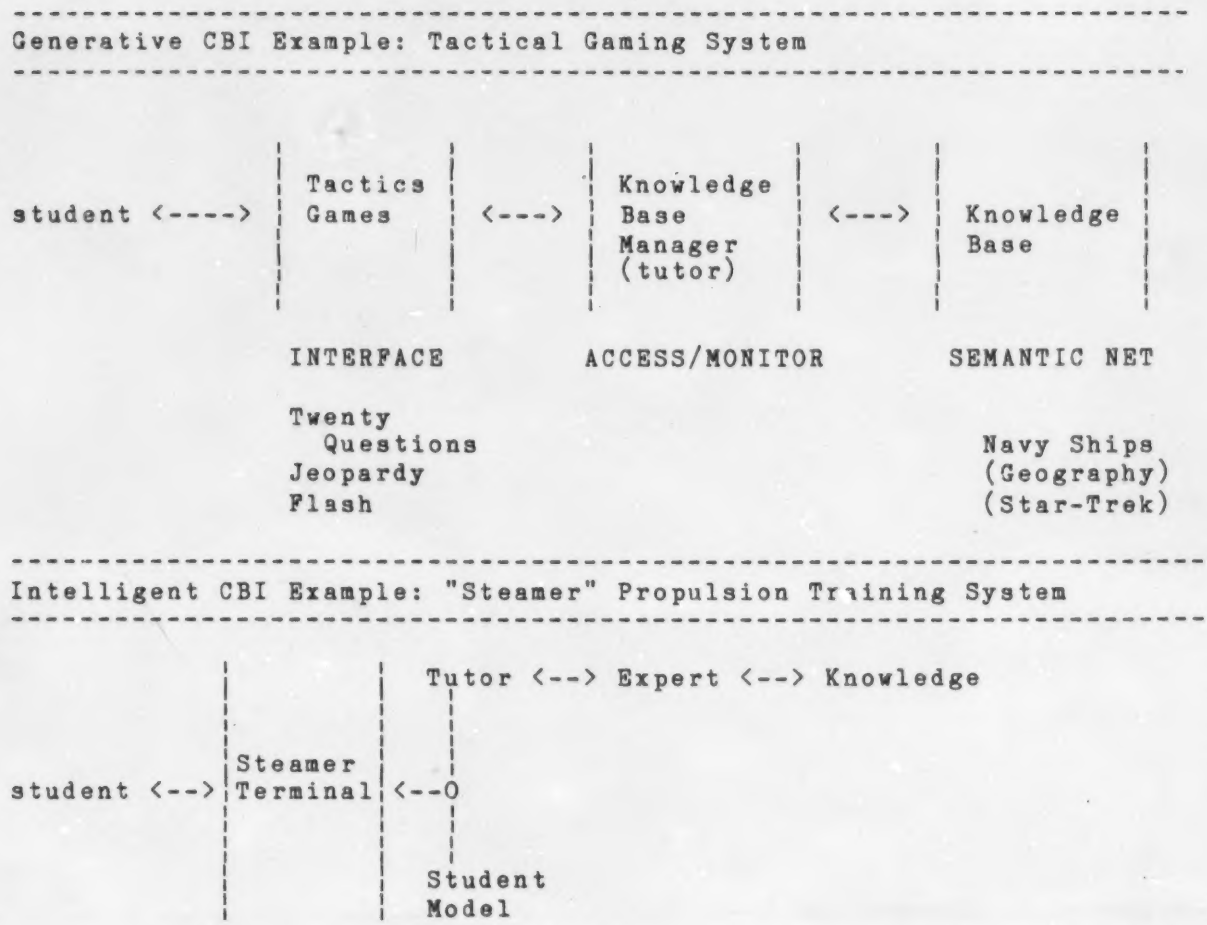


Figure 1. Generative, Intelligent computer-based instruction systems.

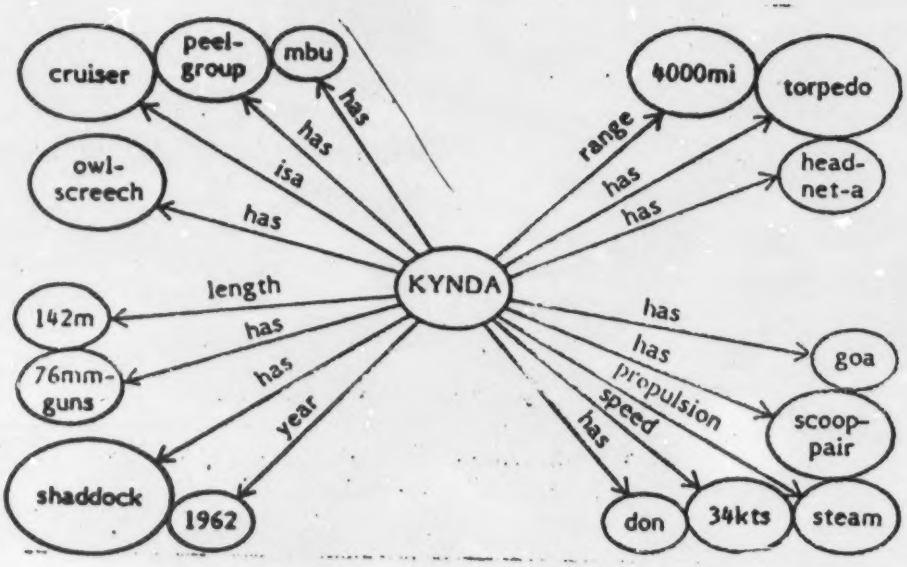


Figure 2. Example of a node (KYNDA) in the semantic network.

KYNDA

has	: owl-screech
has	: peel-group
has	: scoop-pair
has	: head-net
has	: don
has	: mbu
has	: torpedo
has	: 76mm guns
has	: goa
has	: shaddock
range	: 4000mi
speed	: 34kts
propulsion	: steam
length	: 142m
year	: 1962

Figure 3. Description of a KYNDA cruiser retrieved from the database.

list=

<subject>	<relation>	<object>
<kynda>	<has>	<owl-screech>
<kynda>	<has>	<peel-group>
<kynda>	<has>	<scoop-pair>
<kynda>	<has>	<head-net>
<kynda>	<has>	<don>
<kynda>	<has>	<mbu>
<kynda>	<has>	<torpedo>
<kynda>	<has>	<76mm guns>
<kynda>	<has>	<goa>
<kynda>	<has>	<shaddock>

Figure 4. All semantic triangles dealing with <Kynda> <has> <thing>.

PLAYER: You POINTS= 100

Those with	Those without	list of relations	y/n
kirov			
chapaov			
sverdlov			
sverdlov-cn			
sverdlov-cg			
kara			
kresta-2			
kresta-1			
kynda			

Commands: G)uess, S)how, D)isplay, C)omputer guess, H)int, I)s-it-a?

Figure 5. Screen display at the start of a twenty-questions game.

PLAYER: You POINTS= 97

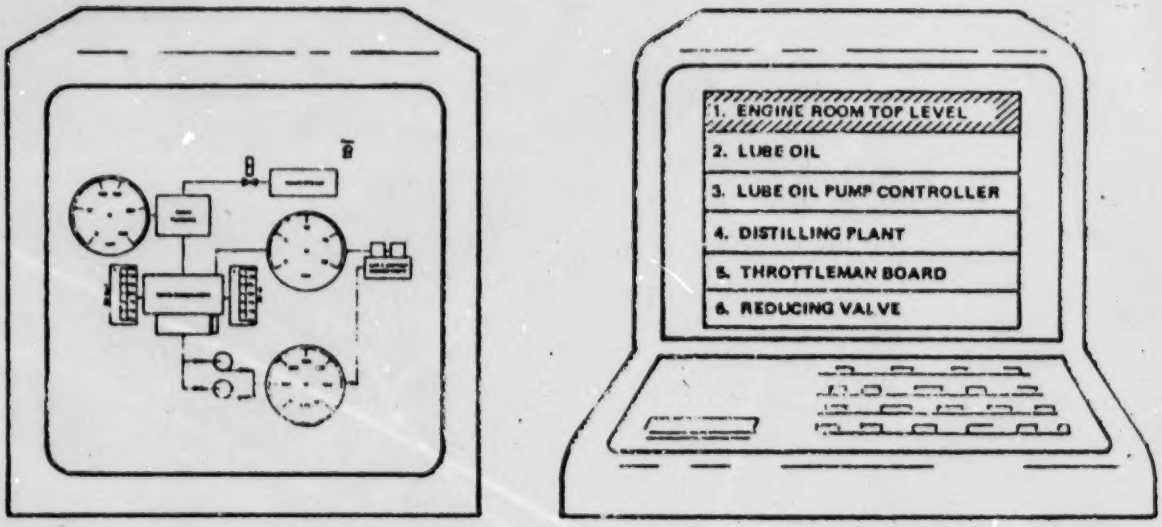
Those with	Those without	list of relations	y/n
sverdlov-cg	kirov	has: tracking-radar	y
sverdlov-cn	chapaov		
kara	sverdlov		
kresta-1	kresta-2		
kynda			

Commands: G)uess, S)how, D)isplay, C)omputer guess, H)int, I)s-it-a?

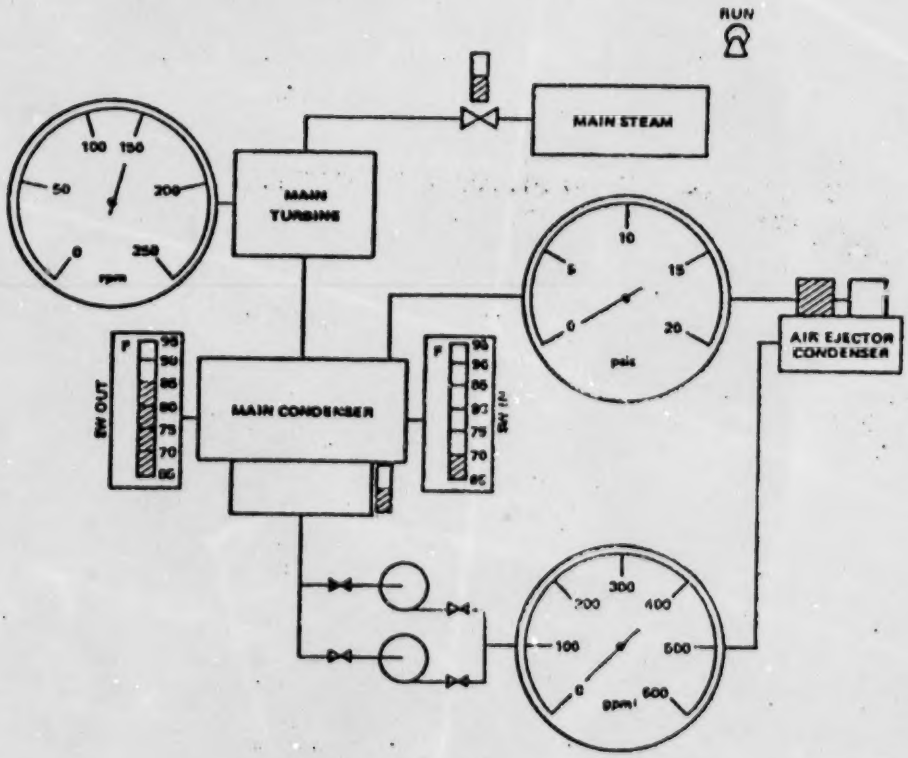
Figure 6. Screen display after one guess in a twenty-questions game.

```
------------------- begin session 5 ------------
Name > James Kirk
Date > 2-12-80
Time > 10:15
Session > 5

***** begin game 1 *****

Database > db_cruisers
Player > James Kirk
looking for >              kirov

clock starts

alternatives > 9

Guess >                    has : scoop-pair        dif= 17.4s.

alternatives > 0

Computer guess(2) >        has : tracking-radar    dif= 60.4s.

Comment > Charting unexplored database (crew on edge)
Comment > Find myself becoming confused until number of
Comment > alternatives is reduced to three or less

alternatives > 4

Hint >                     has : fire-control-radar dif= 18.8s.

Show >                     kresta-2

alternatives > 4

Guess >                    Is-it-a : kresta-2      dif= 7.3s.

alternatives > 3

Guess >                    Is-it-a : kirov         dif= 8.3s.

Final time :  3.92 mins
Total of guesses : 3
Total of regular guesses : 3
Total of hints : 1
Total of computer guesses : 1
Total of shows : 1
Answer > kirov
Final score > 53 points

******** end game 1 **********
------------------ end session 5 ------------
```

Figure 7. Sample audit trail for a twenty-questions game.



The two STEAMER display screens--color (left) for diagrams and black and white (right) for text.



An interactive STEAMER display for the engineroom.

Figure 8. The Steamer displays at the top and a close-up of one at the bottom.

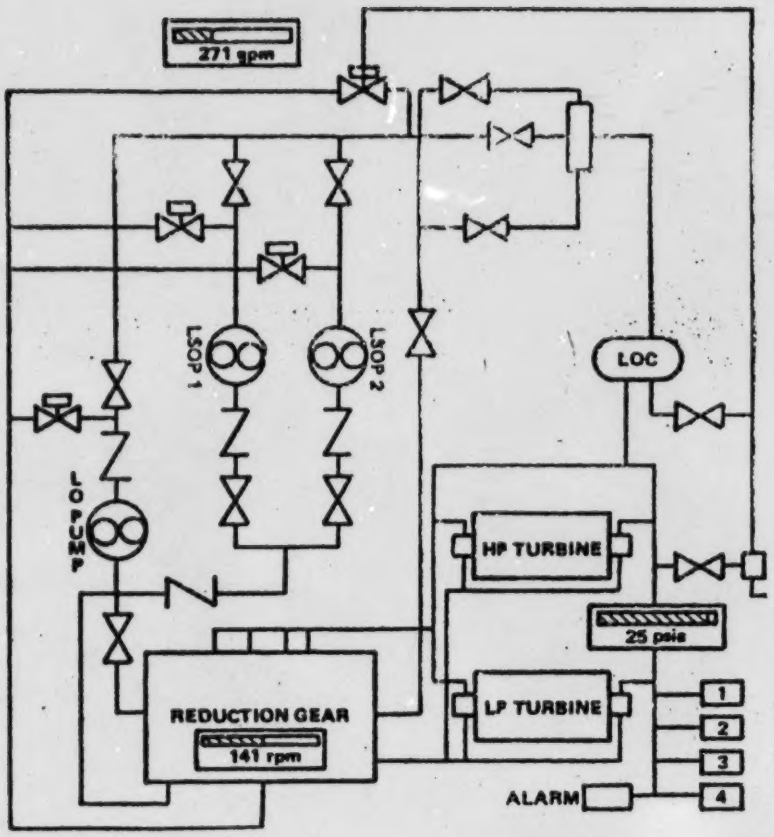


Figure 9. An interactive diagram of the main engine lube oil system.

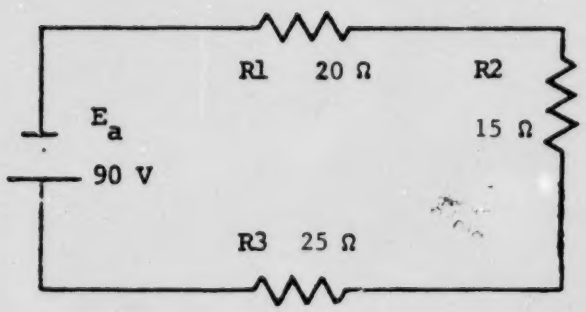


Figure 10. A typical simple series schematic used in teaching basic electronics.

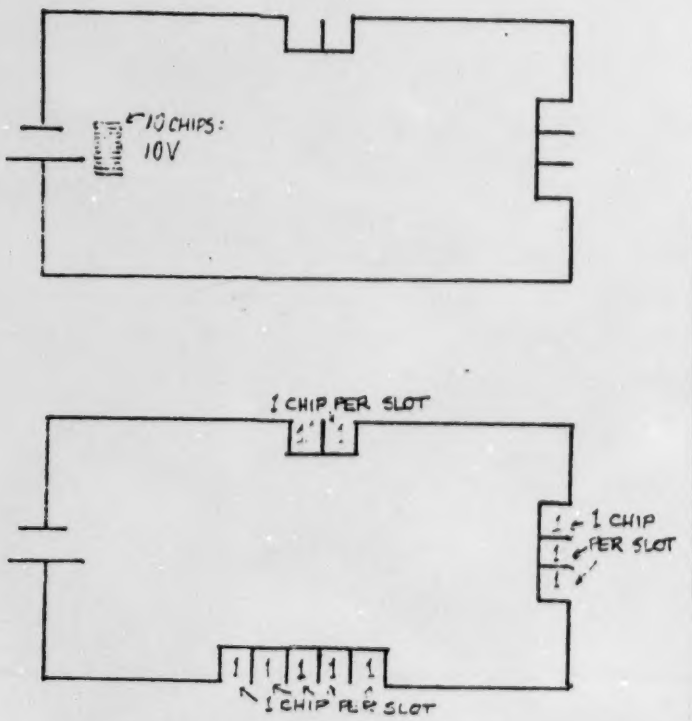
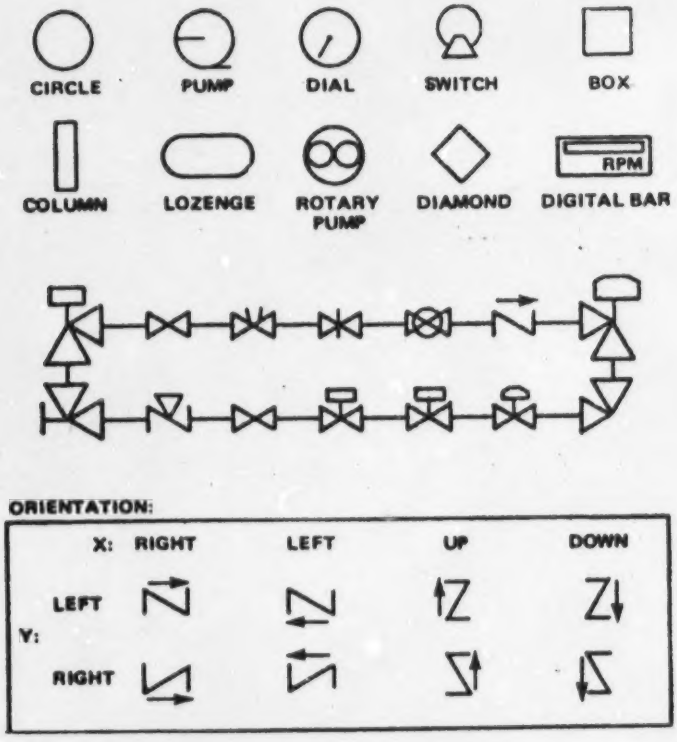
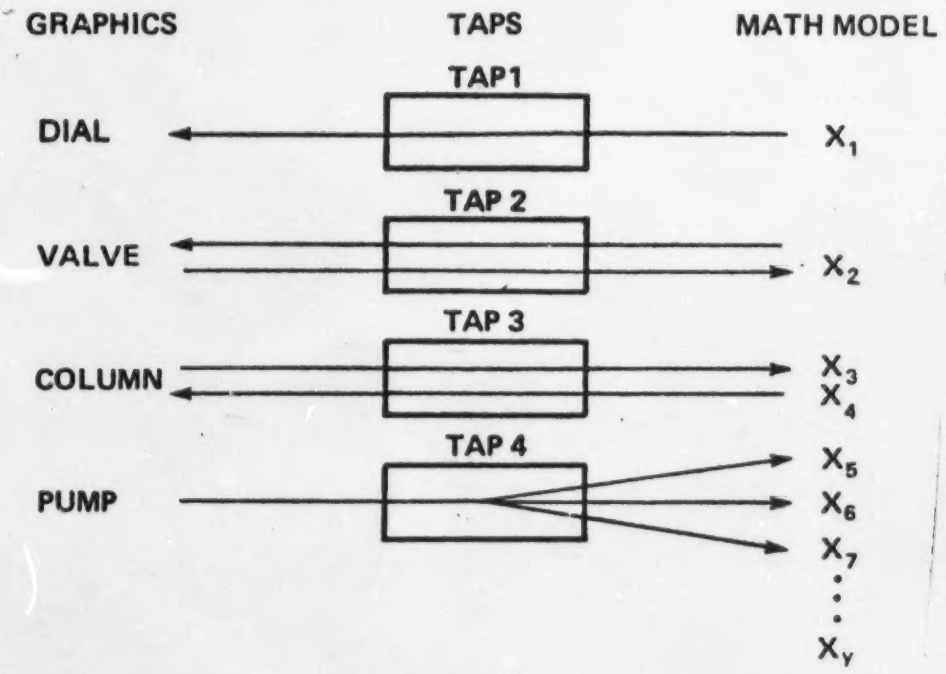


Figure 11. A "chips" representation of a circuit where boxes with slots represent resistors, and poker-chips (volts) are distributed equally in the slots.



A sampler of STEAMER graphical objects.



The relationship between taps, the math model and the Icons.

Figure 12. A schema of how Steamer graphics uses objects and taps them into the math model.